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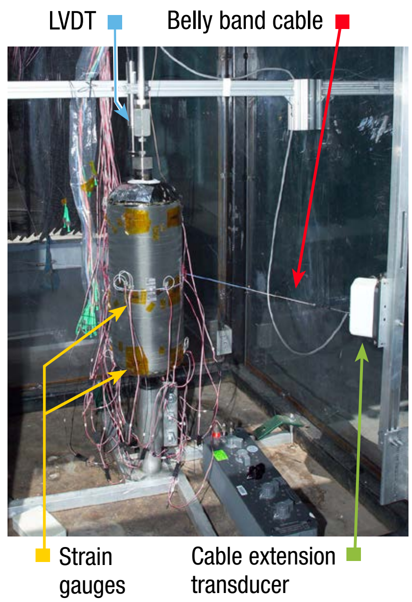
COPV Mechanical Model Validation

Global and local deformation measurements should be incorporated into the composite overwrapped pressure vessel (COPV) design and analysis process to allow correlation of these measurements with finite element analysis (FEA) models. This correlation improves understanding of liner, liner/overwrap interface, and composite deformation response in COPVs. The improved accuracy reduces error in subsequent analyses, such as fracture, fatigue, and stress rupture that are critical for COPV qualification.

Current Obstacles to COPV Mechanical Model Validation

Mechanics models and FEA of COPVs developed by manufacturers have not always been adequate to provide accurate general deformation response and to pinpoint areas of stress concentration in the composite shell and liner. This lack of accuracy has been an obstacle to determining risks associated with failure modes, such as stress rupture and fatigue crack growth. Key phenomena in the understanding of COPV liner and composite response include overwrap stress-deformation states, liner mechanics, and liner/overwrap interface mechanics. Accurate quantification of the interference strain between the liner and overwrap is difficult to capture without measurement and model correlation.



Model correlation study test fixture.

While closed-form solutions and FEA models with simple liner-overwrap interface assumptions may be calibrated to conservatively bound hoop strain response, they cannot accurately capture the complete multi-axial stress and deformation state to simultaneously correlate with all axial, circumferential, and volumetric deformation measurements, especially in the presence of an interface gap. The cited reference identifies ways in which measurements and model correlation can be performed. Global measurements taken from axial linear variable differential transducers (LVDTs), belly bands, and volumetric measurements, along with local measurements of axial and hoop strain from strain gages and laser profilometry measurements, were all demonstrated to be helpful in understanding the complex mechanical response of the COPV. COPVs are classified into 3 levels, and guidelines for measurements are suggested.

Best Practices for Validation of COPV Models

Three levels of measurements are recommended based on design burst safety factors and are intended to serve as guidelines for measurements on flight pressure vessels.

Level 1: Burst factor > 3.0

Determine composite and liner response based on analysis of the vessel per the as-built specifications and demonstrated burst pressure. Alternatively, determine composite and liner response based on closed-form analysis of a measured fiber strain response (nominal or local) as a function of pressure to burst.

Level 2: 2.0 < Burst factor < 3.0

Determine composite and liner response based on fully verified FEA. Measurements needed as a function of applied internal pressure include:

1. **Global measurements:** Axial elongation by LVDT and internal volume growth.
2. **Local measurements:** Hoop and axial strain at equator and other carefully referenced positions by foil strain gages and/or full-field methods of optical metrology.

Level 3: Burst factor < 2.0

Determine composite and liner response based on fully verified finite element model. Measurements needed:

1. **Global measurements:** Axial elongation by LVDT and internal volume growth.
2. **Local measurements:** Hoop and axial strain at equator and other carefully referenced positions by foil strain gages and/or full-field methods of optical metrology.
3. **Interior Laser Profilometry:** Unwound liner, wound liners prior to overwrap cure, wound liner post-overwrap cure prior to autofrettage, and cured COPV post autofrettage.

References

Thesken, J.C., et. al., Composite Pressure Vessel Working Group (CPVWG) Task 4: A Theoretical and Experimental Investigation of Composite Overwrapped Pressure Vessel (COPV) Autofrettage, December 19, 2013. TM-2014-218260.